

RF CAVITIES HOM LONGITUDINAL INSTABILITIES AT SR SOURCE SIBERIA-2 IN KCSR

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Abstract

The electron beam parameters stability and its lifetime depend on the resonant excitation by RF cavities HOMs. The instability rising links with the temperature change, the sequent tune of RF cavities and the synchrotron tune change. Besides that the different intensity bunch distribution along the orbit influences strongly on the instability appearance. For the instability study and their identification the spectrum analyzing is used. The results of instabilities study at SR source Siberia-2 are presented in the report.

INTRODUCTION

Electron beam instabilities at high order modes of oscillations in RF cavities can appear at any storage ring and even can be used for beam parameters manipulations. In this report, situation at Siberia-2 is described. The convenient analytic model of HOM instabilities is developed. The experience of instabilities suppression and control is derived. Siberia-2 is a storage ring dedicated for electron beam storage at injection energy level 450 MeV, acceleration up to 2.5 GeV and standing over a long period of time at high energy level to generate synchrotron radiation. The beam life time can reach at high energy level a few tens of hours. Weak beam instabilities can give here the positive effect – the bunch density decrease and as a consequence the beam life time increase. The same situation is observed sometimes at injection but more often the beam instabilities at injection lead to beam losses. Nevertheless, it is not easy to avoid the resonant conditions at injection. Wide band beam current spectrum (up to 7 GHz) consists of narrow lines spaced equidistantly by comparatively low revolution frequency 2.4 MHz. Storage ring RF system (181 MHz) is based on three RF cavities. Cavities are cooled by water in common cooling circuit without precision temperature stabilization. The fundamental modes of oscillations in cavities are tuned by feedback loops in accordance with beam loading and temperature changes. The HOM frequencies are not controlled automatically. Under these conditions, the HOM frequencies may appear near the lines of densely populated beam current spectrum.

ANALITIC DISCRPTION OF LONGITUDINAL INSTABILITIES AT HIGH ORDER MODES OSCILLATIONS IN RF CAVITIES

To examine the longitudinal stability of rigid bunches circulating in the storage ring and interacting with one of the high modes of oscillations in RF cavities, the set of

the linear equations for small phase deviations φ_m of bunches from synchronous values can be written as

$$\ddot{\varphi}_m + \Omega_0^2 \varphi_m + \frac{\Omega_0^2}{V_{RF} \cos \varphi_{s0}} \cdot \text{Im} \sum_{n=1}^h \frac{R_{shq} I_{qn} e^{iq \frac{2\pi}{h} (m-n)}}{1 + i\eta_{qs}} \frac{q}{h} \times \\ \times \left(\varphi_m - \varphi_n + \frac{2\pi}{h\omega_s} (m-n) \left(\dot{\varphi}_m - \dot{\varphi}_n \right) + \frac{2Q_q}{\omega_q (1+i\eta_{qs})} \dot{\varphi}_n \right) = 0.$$

The set consists of h equations ($m = 1, 2, \dots, h$) where h is the RF harmonic number, V_{RF} and Ω_0 are the RF voltage and correspondingly the synchrotron oscillations frequency in absence of high order mode excitation. For problem discussed, the dominant circumstance is that some harmonic $q\omega_s$ of beam revolution frequency ω_s is almost equal to frequency ω_q of some mode in RF cavities. For this mode, the shunt impedance R_{shq} , the quality factor Q_q and the detuning factor

$$\eta_{qs} = 2Q_q \frac{q\omega_s - \omega_q}{\omega_q}$$

are used in equations. The bunch intensities are introduced as the doubled bunch circulating currents I_{qn} , $n = 1, \dots, h$. The phase equations are worked out under the assumption that every n -th bunch excites in the cavity the field at the frequency $q\omega_n$ where

$$\omega_n = \omega_s - \frac{1}{h} \dot{\varphi}_n$$

is the circulating frequency of the bunch in the ring. The complex (with respect to the bunch current) amplitude of bunch excited voltage

$$V_{qmn} = -\frac{R_{shq} I_{qn}}{1 + i\eta_{qn}},$$

$$\eta_{qn} = 2Q_q \frac{q\omega_n - \omega_q}{\omega_q} = 2Q_q \frac{q\omega_s - \frac{q}{h} \dot{\varphi}_n - \omega_q}{\omega_q}. \quad \text{Thus}$$

the excited voltage for the bunch is fully braking if the bunch excites the cavity at its resonant frequency, $V_{qmn} = -R_{shq} I_{qn}$. The set of the phase equations presents

the standard mathematical problem and can be solved by standard methods in general. At the same time, in particular cases equations allow the simple interpretations. For example, in the particular case for one bunch on the orbit (Robinson instability when $q = h$), the set of phase equations is reduced to one equation,

$$\ddot{\varphi} + \Omega_0^2 \varphi + \frac{\Omega_0^2}{V_{RF} \cos \varphi_{s0}} \frac{R_{shq} I_q q 2 Q_q}{h \omega_q} \dot{\varphi} \operatorname{Im} \frac{-2i \eta_{qs}}{(1 + \eta_{qs}^2)^2} = 0.$$

The solution stability condition here is the non-negative coefficient of $\dot{\varphi}$, that is $\frac{-(q\omega_s - \omega_q)}{\cos \varphi_{s0}} \geq 0$. In the other

case for k identical bunches oscillating in phase and under condition that bunches interact at RF frequency ($q = h$) or its harmonic (q is h multiple), the phase equation is the same as above but the instability increment (if instability arises) is proportional to the full beam current.

HOM INSTABILITIES IN STORAGE RING SIBERIA-2

Longitudinal instabilities at high order modes in Siberia-2 are not the dominant processes which can reduce such main parameters of the ring like accelerated beam current or beam life time. At the same time, the instabilities appearance or development can be continuously controlled for successful beam storage and beam energy rising. For measurements and beam diagnostics, the systems and devices are used:

- Wide band (up to 5 GHz) system for observation and measurements of bunch current distributions along the orbit.
- Optical system for integrated in time visualization of beam cross section particle distributions by TV camera.
- Dissector in stroboscope regime (50 Hz) for bunch longitudinal particle distribution measurements.
- Wide band (up to 13.5 GHz) spectrum analyser for precision measurements.

For precision spectrum measurements, signals from coupling loops in cavities and beam current monitors in vacuum chamber are used. Every RF cavity contains four tuning elements – two elements for the fundamental mode and two elements for high order modes. It is important, that elements are not rigorously independent. The fundamental mode tuning causes small changes of high order modes frequencies. The main HOMs quality factors are comparable with the fundamental mode quality factor. The example of field spectrum in RF cavity is given at Fig. 1. The field is excited by power amplifier (181.1 MHz) and beam current at harmonics of revolution frequency (2.41 MHz). The amplifier excites the RF voltage harmonics only and on the levels less then -80 dB with respect to fundamental frequency. Rich spectrum in cavity is excited by the beam. At the instability, the level of active mode can reach -10 dB with respect to fundamental mode. The narrow spectrum of beam current illustrates at Fig. 2 the development of instability. The second pair of sides may indicate the quadrupole instability rising. Instability mode is determined by dissector.

CONCLUSION

HOM instabilities appear at injection and in the narrow regions of beam currents. Practical approach here is to overcome the narrow instability regions.

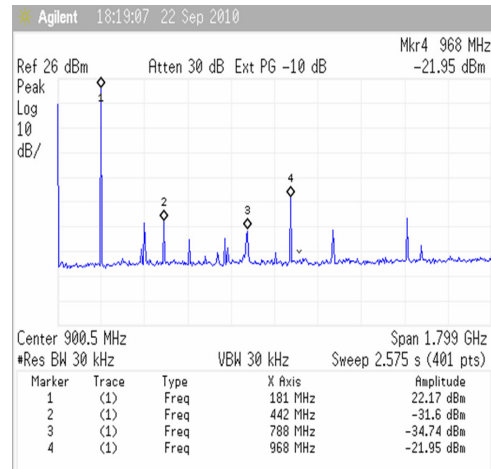


Figure 1: Field spectrum in RF cavity.

At storage ring Siberia-2, the tactics consist of: detuning of active high order modes to the optimal positions; increasing the intensity of injected bunches (to decrease

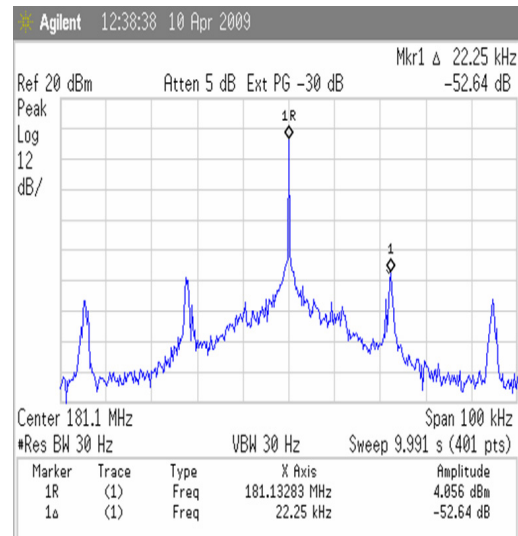


Figure 2: Beam current spectrum.

the time of being at instability regions); in the cavity with active high order mode, changing of the programmable phase (to detune the high order mode); in the cavity with active high order mode, increasing of the programmable RF voltage (to detune the high order mode), changing of bunch distribution along the orbit. As a cardinal solution of problem, the wide band feedback system is assumed at Siberia-2.